Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

Hwang, Hyeon-Shik; Choe, Seon-Yeong; Hwang, Ji-Sup; Moon, Da-Nal; Hou, Yanan; Lee, Won-Joon; Wilkinson, Caroline

Published in:
Journal of Forensic Sciences

DOI:
10.1111/1556-4029.12766

Publication date:
2015

Document Version
Peer reviewed version

Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

Hou, Yanan; Choe, Seon-Yeong; Hwang, Ji-Sup; Moon, Da-Nal; Lee, Won-Joon; Wilkinson, Caroline; Hwang, Hyeon-Shik

Published in:
Journal of Forensic Sciences

Publication date:
2014

JOURNAL OF FORENSIC SCIENCES

Reproducibility of facial soft tissue thickness measurements using cone-beam CT images according to measurement methods

Journal:	*Journal of Forensic Sciences*
Manuscript ID:	JOFS-14-057.R1
Manuscript Type:	Technical Note
Date Submitted by the Author:	20-Jun-2014
Complete List of Authors:	Hou, Yanan; Chonnam National University, Orthodontics Choe, Seon-Yeong; Chonnam National University, Hwang, Ji-Sup; Seoul National Univeirsity, Moon, Da-Nal; Chonnam National University, Orthodontics Lee, Won-Joon; Seoul National University, Anatomy Wilkinson, Caroline; University of Dundee, Centre for Anatomy & Human Identification Hwang, Hyeon-Shik; Chonnam National University, Orthodontics
Keywords:	forensic science, facial reconstruction, soft tissue thickness, reproducibility, cone-beam computed tomography, three-dimensional image

Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

Yanan Hou,[1] *D.D.S.;* Seon-Yeong Choe,[2] *B.A.;* Ji-Sup Hwang,[3] *B.A.;* Da-Nal Moon,[1] *D.D.S.;* Won-Joon Lee,[4] *Ph.D.;* Caroline Wilkinson,[5] *Ph.D.; and* Hyeon-Shik Hwang,[6] *Ph.D.;*

[1] Graduate Student, School of Dentistry, Chonnam National University, Gwangju, Korea

[2] Student, School of Dentistry, Chonnam National University, Gwangju, Korea

[3] Student, College of Medicine, Seoul National University, Seoul, Korea

[4] Institute of Forensic Science, College of Medicine, Seoul National University, Seoul, Korea

[5] Professor of Craniofacial Identification, Centre for Anatomy and Human Identification, College of Life Sciences, University of Dundee, Dundee, United Kingdom

[6] Professor and Chairman, Department of Orthodontics, School of Dentistry, Dental Science Research Institute, Chonnam National University, Gwangju, Korea

Corresponding author:

Dr. Hyeon-Shik Hwang
Department of Orthodontics
Chonnam National University School of Dentistry
33 Yongbong-ro, Buk-gu
Gwangju 500-757, KOREA
Room: +82-62-530-5841 Fax: +82-62-530-0393
E-mail: hhwang@chonnam.ac.kr

Acknowledgements
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2010-0025828).

Reproducibility of Facial Soft Tissue Thickness Measurements using Cone-Beam CT Images According to Measurement Methods

ABSTRACT: The purpose of this study was to establish the reproducibility of facial soft tissue (ST) thickness measurements by comparing three different measurement methods applied at 32 landmarks on three-dimensional cone-beam computed tomography (CBCT) images. Two observers carried out the measurements of facial ST thickness of 20 adult subjects using CBCT scan data, and inter- and intra-observer reproducibility were evaluated. The measurement method of 'perpendicular to bone' resulted in high inter- and intra-observer reproducibility at all 32 landmarks. In contrast, the 'perpendicular to skin' method, and 'direct' method which measures a distance between one point on bone and the other point on skin presented low reproducibility. The results indicate that reproducibility could be increased by identifying the landmarks on hard tissue images, rather than on ST images, and the landmark description used in this study can be used in the establishment of reliable tissue depth data using CBCT images.

KEYWORDS: forensic science, facial reconstruction, soft tissue thickness, reproducibility, cone-beam computed tomography, three-dimensional image

In forensic facial reconstruction, the facial features of unknown individuals are estimated from an unidentified skull (1,2). In order to recreate an individual's face, the establishment of reliable facial soft tissue (ST) thickness data is necessary. In the past, such reference data were obtained from needle puncture measurement on cadavers, which has been criticized due to some inevitable differences between cadaver-based and in-vivo measurements relating to post-mortem tissue changes such as dehydration and shrinkage (2-4). For large-scale studies on ST thickness measurements, ultrasound has been utilized, which has its advantages in cost and accessibility, but has its drawbacks in being time-consuming and in that additional measurements cannot be made at a later date (3,5-8).

To overcome these disadvantages, computed tomography (CT) has been used to measure the ST thickness. Use of a three-dimensional (3D) image program allowed the realization of 3D images of facial soft tissues as well as hard tissues. ST thickness can be measured as a distance between a point of the soft tissue and its corresponding point on the hard tissue image. Kim et al. (9) reported that CT images can be used to accurately measure the ST thickness in the facial region. Despite this, widespread use was limited because of high radiation dose and gravity-related effects on soft tissues of the subjects in a supine position (8,10,11). Recently-developed cone-beam CT (CBCT), however, enables us to obtain images with the subjects in an upright position and the reported radiation dose is much less in a CBCT scan compared to multi-slice CT (8,10-13). Fourie et al. (14) showed that the facial ST thickness can be measured on CBCT images with high accuracy through comparison with digital caliper measurements using cadaver subjects. Hwang et al. (15) reported that the CBCT images can be used to measure the ST thickness with high reproducibility in their study using living subjects.

While forensic facial reconstruction is a process of rebuilding facial soft tissues onto the surface of an unidentified skull, CBCT gives us information about both soft and hard tissues, and the ST thickness can, therefore, be measured along a line where the starting point is either on the ST, on the hard tissue, or on both. While a reliable tissue depth data is needed for a facial reconstruction, there has been little study regarding the reproducibility of ST thickness measurements, particularly its differences according to the measurement methods. The purposes of this study were to evaluate the reproducibility of ST thickness measurements on 3D CBCT images, and to compare the reproducibility according to three different measurement methods: (1) measurement taken 'perpendicular to bone', (2) measurement taken 'perpendicular to skin', and (3) 'direct measurement' which measures a distance between a point of the bone and its corresponding point of the skin image.

Materials and Methods

Twenty adult individuals (10 males, 10 females) without facial asymmetries and deformities were used as the subjects of this study. This research was approved by the Institutional Review Board for the Medical Science at the Chonnam National University Hospital, Gwangju, Korea. Informed consent was obtained from all subjects. The mean age of the subjects was 27.6 years. The CT scans were obtained using a CBCT scanner (Alphard Vega: Asahi Roentgen Co., Kyoto, Japan), with a voxel size of 0.39 mm and a field of view of 200 x 179 mm. The subject was scanned in the seated position with a neutral, relaxed facial expression. The maxillofacial 3D images were created from DICOM data using V Works 4.0 (CyberMed, Seoul, Korea). A pair of 3D object files was created with an adjustment of the

Hounsfield units (HU): one for the hard tissue image with 550~650 HU and another for the ST image with -570 to -550 HU.

Landmark Selection and Description

In order to evaluate the reproducibility of ST thickness measurements, 32 (8 midline and 24 bilateral) landmark sites were selected as in Figures 1 and 2. All landmarks were selected with a pair, one on hard tissue and another on soft tissue, so that they correspond to each other. The landmarks were first adopted from De Greef et al. (7) which performed a large-scale study at a number of landmark sites using ultrasound system, and then modified according to Hwang et al. (15) which used CBCT images for the measurement of ST thickness. An emphasis was placed on increasing reproducibility in landmark identification. In cases where the ST landmark was not able to be delineated from 3D CBCT image, it was defined as the point on the skin extrapolated by a perpendicular line from its hard tissue counterpart. The name and description of the landmarks are seen in Tables 1 and 2 (Figs. 1 and 2, Tables 1 and 2).

Measurement of Soft Tissue Thickness

In order to obtain ST thickness measurement, a specific software named Skull Measure (CyberMed, Seoul, Korea) was used in this study (15,16). Both soft and hard tissue images reconstructed from CBCT scan data were imported into the software program in order to measure the distance between a point on the hard tissue image and corresponding point on the ST image. The ST thickness was measured using three different methods: (1) measurement taken 'perpendicular to bone', (2) measurement taken 'perpendicular to skin', and (3) 'direct measurement' which measures a distance between a point on bone and another point on skin.

For the 'perpendicular to bone' method, the landmarks were identified on the hard tissue images according to the definition of hard tissue landmarks. Then, the corresponding points were designated automatically on the ST images as to meet the line starting perpendicularly from the identified hard tissue point. The computer calculated the distance between the two points using Euclidean distance (Fig. 3A). For the 'perpendicular to skin' method, the landmarks were identified on the soft tissue images according to the ST landmark definitions. Once a point is identified on the ST image, the corresponding point is designated automatically on the hard tissue image by the program. The distance between the two points is obtained as the ST thickness (15,16) (Fig. 3B). In case of 'direct measurement', one point was identified on the hard tissue image, and the corresponding point was established on the ST image according to the landmark definitions. In other words, both hard and soft tissue landmarks were identified by the investigator. The distances between the two points were calculated by the program as the ST thickness with the 'direct measurement' method (Fig. 3C).

All three measurements were carried out by one observer to find if the results differ according to the methods. Another observer followed the same measurement protocol to evaluate the inter-observer reproducibility, and one of the observers performed the measurement twice with a 3-week interval to evaluate the intra-observer reproducibility.

Statistical Analysis

The means and standard deviation of the measurements for all three measurement methods were calculated. The three measurement methods were then compared using ANOVA. To calculate the inter-observer reproducibility, a paired *t*-test and intraclass correlation analysis

were used. A paired *t*-test was used to calculate the intra-observer reproducibility. The correlation coefficients were calculated using Pearson correlation and reliability coefficient analyses. Statistical data analysis was carried out using SPSS software, version 17.0 for Windows (SPSS Inc, Chicago, IL).

Results

Comparison of the Measurement According to Methods

Table 3 shows the results of the calculation of means, standard deviations and ANOVA at each landmark. Sixteen out of 32 landmarks were identified with statistically significant differences between the three measurement methods (Table 3).

Inter-observer Reproducibility According to Methods

Tables 4, 5, and 6 show the results of paired *t*-test and intraclass correlation analysis showing the inter-observer reproducibility in case of 'perpendicular to bone' method, 'perpendicular to skin' method, and 'direct measurement' method, respectively.

In the 'perpendicular to bone' method, there were no significant differences between the two observers for all landmark measurements. The results of intraclass correlation analysis at all landmarks were >0.7, indicating high reproducibility for the 'perpendicular to bone' method (Table 4).

In case of 'perpendicular to skin' method, the results of the *t*-test identified 14 out of 32 landmarks with significant differences and intraclass correlation analysis showed that

correlation coefficients of 9 landmarks were <0.7. Some landmarks showed low reproducibility for either *t*-test or intraclass correlation analysis, whereas 6 landmarks (ST B point, ST Mental tubercle, ST Mid-lateral orbit, ST Supra-M1, ST Infra-M1, ST Sub-mandibular) were identified with low reproducibility for both *t*-test and intraclass correlation analysis (Table 5).

In case of 'direct measurement' method, the results of the *t*-test identified 18 out of 32 landmarks with significant differences, which was higher than the other two measurement methods. Intraclass correlation analysis showed 13 landmarks with the correlation coefficients less than 0.7, indicating the lowest reproducibility among the three measurement methods (Table 6).

Intra-observer Reproducibility According to Methods

Tables 7, 8, and 9 show the results of the evaluation of intra-observer reproducibility in case of 'perpendicular to bone', 'perpendicular to skin', and 'direct measurement', respectively.

In case of 'perpendicular to bone' method, no significant differences were found between the two measurements when analyzed using t-test, and the results of correlation analyses also showed high values, 0.826~0.994 and 0.904~0.996 for Pearson correlation analysis and reliability analysis respectively, indicating high reproducibility for the 'perpendicular to bone' method (Table 7).

In case of 'perpendicular to skin' method, the results of the *t*-test identified 1 landmark with a significant difference. While most landmarks showed statistically significant correlations

between the two measurements for the Pearson correlation and reliability analyses, three landmarks (ST Lateral nasion, ST Lateral rhinion, ST Supra-M1) showed low reproducibility (Table 8).

In case of 'direct measurement' method, the reproducibility showed high values, 0.636~0.969 and 0.768~0.985 for Pearson correlation analysis and reliability analysis respectively. However, the results of the *t*-test showed several landmarks with statistically significant differences between the two measurements, which indicated lower reproducibility than 'perpendicular to bone' method (Table 9).

Discussion

Use of CBCT creates images of both soft and hard tissues according to computer algorithm, and this makes possible for the ST thickness measurements to be based not only on soft tissues but also on hard tissues. Moreover, hard and soft tissues can together be the basis if the ST thickness measurements are carried out by directly calculating the distance between two landmarks, one on the image of hard tissues and the other on the image of soft tissues. After Kim et al. (9) reported that CT images are accurate for the measurement of facial ST thickness, Hwang et al. (15) used CBCT to make measures and reported on the reproducibility of these results according to landmarks. The study showed a generally high reproducibility of the measurements and suggested the potentialities of using CBCT for accurate measurement of facial ST thickness. However, on some of the landmarks, it reported low reproducibility as well, and the reason for this result might have been due to the use of landmarks that are defined for studies using ultrasound, not CBCT, as their measurement

device. This study, therefore, modified these landmarks into what CBCT investigators can identify on their 3D images of soft and hard tissues with high consistency, and compared the reproducibility of facial ST thickness measurements according to three different measurement methods, so that a reasonable measurement protocol can be established.

Comparison of the above 3 measurements by ANOVA showed that 16 out of 32 landmarks presented with statistically significant differences between the methods. In other words, the ST thickness measurements differed according to the measurement methods. This result indicates that description on the used measurement method should be stated together if the measurement data were obtained with CBCT images.

As the results of *t*-test and intraclass correlation analysis, 'perpendicular to bone' method showed higher inter-observer reproducibility than the other two methods. In case of 'perpendicular to bone' method, no significant difference was seen at all landmarks according to *t*-test, and intraclass correlation analysis resulted in correlation coefficients higher than 0.7 at all landmarks, as well. In case of 'perpendicular to skin' method and 'direct measurement' method, however, several landmarks were identified with significant differences by *t*-test. The results of intraclass correlation analysis also showed smaller value of correlation coefficients than in case of 'perpendicular to bone'. The reason for higher inter-observer reproducibility of 'perpendicular to bone' method than that of 'perpendicular to skin' method seems to lie in clearness of landmark definitions. Anatomical structures are easily identified on hard tissues whereas a landmark is not identified easily on soft tissue surface. As examples, landmarks such as ST Mental tubercle and ST Mid-lateral orbit did not clearly represent the actual anatomical structure of soft tissues and thus were identified with low inter-observer

reproducibility. Meanwhile, their corresponding landmarks on hard tissues, which were Mental tubercle and Mid-lateral orbit respectively, clearly expressed their actual anatomical structures which can be verified by the high reproducibility of the measurements. Farkas (17) and Cavalcanti et al. (18) examined both the hard and soft tissue landmarks in the 3D images, and reported that the hard tissue points were easier to localize than soft tissue landmarks. All these results suggest that approach based on hard tissue, rather than ST, would be better for obtaining reliable tissue depth data using CBCT images.

Other landmarks that were identified with low inter-observer reproducibility in case of using 'perpendicular to skin' method were proven to be located where variations in ST thickness are great between the subjects. Among previous studies using ultrasound systems, Manhein et al. (3), Wilkinson (6), and De Greef et al. (7) reported on high standard deviations identified for the ST thickness measurements made at cheek area. Also in this study, the landmarks located at the cheek area, such as ST Supra-M1 and ST infra-M1 showed large standard deviations and low reproducibility.

On the other hand, the intra-observer reproducibility showed higher values than the inter-observer reproducibility regardless of the measurement methods. In case of 'perpendicular to skin' method, inter-observer reproducibility showed 14 landmarks with significant differences based on *t*-test and 9 landmarks with intraclass coefficients smaller than 0.7. However, intra-observer reproducibility presented only 1 landmark with significant difference and 3 landmarks with low correlation coefficients indicating a higher intra-observer reproducibility than the inter-observer reproducibility. Also, in case of 'direct measurement' method, inter-observer comparison showed 18 landmarks with significant differences whereas intra-

observer reproducibility presented only 9 landmarks with significant differences based on *t*-test. The reason of higher reproducibility in the intra-observer evaluation than in the inter-observer evaluation seems to be that identifying landmarks is a subjective process, and can be affected by individual's recognition of anatomical structures. Regardless of the difference of reproducibility between inter- and intra-observer evaluation, 'perpendicular to bone' method was superior to other two measurement methods in both intra- and inter-observer reproducibility. This indicates that landmarks on hard tissues are more objectively recognized than landmarks on soft tissues are.

Analysis of intra-observer reproducibility in case of 'direct measurement' method, which uses two manually identified landmarks on soft and hard tissue image each, resulted in generally high values by Pearson correlation analysis and reliability analysis, but several landmarks showed significant differences by *t*-test. However, the actual differences between the averages of first and second measurements at these landmarks were of more or less than 0.5mm, a clinically insignificant value. It is believed that 'direct measurement' method might be used as a reliable method when needed. In addition, this measurement method has another advantage of short measurement time, compared to the other two methods where repeated measurements required until the automatically designated points suit the definition of landmarks.

The results of the present study indicate that the ST thickness measurements using CBCT images show the highest reproducibility when they are obtained by 'perpendicular to bone' method. This finding is believed to be a favorable result to actual forensic facial reconstruction considering that soft tissues are built on to the surface of hard tissue. However,

the measurement data of 'perpendicular to skin' or 'direct measurement' method might be required in some landmark areas for a facial reconstruction. The ST thickness data in CBCT images should be established according to all three methods, 'perpendicular to bone', 'perpendicular to skin', and 'direct measurement' between bone and skin, and the present study can be a good reference on evaluating the reliability of each measurement method. The measurement methods in this study can be used reasonably in the establishment of reliable tissue depth data using CBCT images.

References

1. Snow CC, Gatliff BP, McWilliams KR. Reconstruction of facial features from the skull: an evaluation of its usefulness in forensic anthropology. Am J Phys Anthropol 1970;33(2):221-8.

2. Wilkinson CM. Forensic Facial Reconstruction. Cambridge: Cambridge University Press 2004;39-48.

3. Manhein MH, Listi GA, Barsley RE, Musselman R, Barrow NE, Ubelaker DH. In vivo facial tissue depth measurements for children and adults. J Forensic Sci 2000;45(1):48-60.

4. De Greef S, Willems G. Three-dimensional cranio-facial reconstruction in forensic identification: latest progress and new tendencies in the 21st century. J Forensic Sci 2005;50(1):12-7.

5. El-Mehallawi IH, Soliman EM. Ultrasonic assessment of facial soft tissue thicknesses in adult Egyptians. Forensic Sci Int 2001;117(1-2):99-107.

6. Wilkinson CM. In vivo facial tissue depth measurements for white British children. J Forensic Sci 2002;47(3):459-65.

7. De Greef S, Claes P, Vandermeulen D, Mollemans W, Suetens P, Willems G. Large-scale in-vivo Caucasian facial soft tissue thickness database for craniofacial reconstruction. Forensic Sci Int 2006;159:126-46.

8. Plooij JM, Maal TJ, Haers P, Borstlap WA, Kuijpers-Jagtman AM, Bergé SJ. Digital three-dimensional image fusion processes for planning and evaluating orthodontics and orthognathic surgery. A systematic review. Int J Oral Maxillofac Surg 2011;40(4):341–52.

9. Kim KD, Ruprecht A, Wang G, Lee JB, Dawson DV, Vannier MW. Accuracy of facial soft tissue thickness measurements in personal computer-based multiplanar reconstructed computed tomographic images. Forensic Sci Int 2005;155(1):28-34.

10. Sukovic P. Cone beam computed tomography in craniofacial imaging. Orthod Craniofac Res 2003;6:31–6.

11. Mah JK, Danforth RA, Bumann A, Hatcher D. Radiation absorbed in maxillofacial imaging with a new dental computed tomography device. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96(4):508-13.

12. Tsiklakis K, Donta C, Gavala S, Karayianni K, Kamenopoulou V, Hourdakis CJ. Dose reduction in maxillofacial imaging using low dose Cone Beam CT. Eur J Radiol 2005;56(3):413-7.

13. Swennen GR, Schutyser F. Three-dimensional cephalometry: spiral multi-slice vs

cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2006;130(3):410-6.

14. Fourie Z, Damstra J, Gerrits PO, Ren Y. Accuracy and reliability of facial soft tissue depth measurements using cone beam computer tomography. Forensic Sci Int 2010:15;199(1-3):9-14.

15. Hwang HS, Kim K, Moon DN, Kim JH, Wilkinson C. Reproducibility of facial soft tissue thickness for craniofacial reconstruction using cone-beam CT images. J Forensic Sci 2012;57(2):443-8.

16. Hwang HS, Park MK, Lee WJ, Cho JH, Kim BK, Wilkinson C. Facial soft tissue thickness database for craniofacial reconstruction in Korean adults. J Forensic Sci 2012;57(6):1442-7.

17. Farkas LG. Anthropometry of the Head and Face. New York: Raven Press, 1994.

18. Cavalcanti MG, Rocha SS, Vannier MW. Craniofacial measurements based on 3D-CT volume rendering: implications for clinical applications. Dentomaxillofac Radiol 2004;33(3):170-6.

TABLE 1 - *Description of hard tissue landmarks used for soft tissue thickness measurement using cone-beam CT images.*

Landmarks[†]		*Description*
Midline landmarks		
1	Glabella	Most anterior point of forehead
2	Infra-glabella	Crosspoint between the midline and the line connecting both superior orbital margins
3	Nasion	Midpoint of the fronto-nasal suture
4	Rhinion	Tip of nasal bone
5	Mid-philtrum	Inferior one third of the line between anterior nasal spine and supradentale
6	B point	Most posterior point of bony curvature of the mandible between infradentale and pogonion
7	Pogonion	Most anterior point on the bony contour of the chin
8	Menton	Most inferior point on the bony contour of the chin
Bilateral landmarks		
9	Frontal eminence	Most anterior point of the frontal bone, horizontally centered on the orbit
10	Supra-orbit	Horizontally centered on the orbit, just above superior orbital margin
11	Lateral nasion	Below the midpoint of fronto-maxillary suture
12	Lateral nasal end	Vertically at the level of end of nasal bone and horizontally on a vertical line with the mesial wall of the orbital rim
13	Infra-orbit	Horizontally centered on the orbit, under inferior orbital margin
14	Maxillare	Maximum concavity point on maxilla, centered on the orbit, just under the zygomatic process of maxilla
15	Lateral nostril	Vertically at the level of bottom of nasal aperture, and horizontally on a vertical line with the lateral margin of the aperture
16	Incisor alveolus	Inferior one third of nasal floor and alveolar margin of the central incisor
17	Supra-canina	Most prominent point on alveolar margin of upper canine
18	Upper incisor	Central point on labial surface of upper central incisor crown
19	Lower incisor	Central point on labial surface of lower central incisor crown
20	Infra-canina	Most prominent point on alveolar margin of lower canine
21	Mental tubercle	Most prominent point on the mental tubercle
22	Mid-lateral orbit	Vertically centered on the orbit, next to the lateral orbit border
23	Supraglenoid	Root of the zygomatic arch above the condylar head
24	Zygomatic arch	Most lateral curvature of the zygomatic arch
25	Lateral zygoma	Center of the zygoma, horizontally lined up with the lateral border of the orbital rim
26	Supra-M1	Most prominent point on alveolar margin of the maxillary first molar
27	Ante-ramus	Anterior border of the mandibular ramus at the level of occlusal plane
28	Mid-ramus	Center of the ramus, horizontally middle point between anterior and posterior border of mandibular ramus, vertically the halfway point between mandibular notch and antegonial notch
29	Infra-M1	Most prominent point on alveolar margin of the mandibular first molar
30	Gonion lateralis	Most lateral point on gonial area
31	Mid-mandibular	Center of the mandibular body, horizontally lined up with mandibular first molar and vertically at the level of mental foramen
32	Sub-mandibular	Most lateral point on the inferior border of the mandible at the level of mandibular first molar

[†]The number which precedes the landmark name is corresponded to the number represented in the Figure 1.

TABLE 2 - *Description of soft tissue landmarks used for soft tissue thickness measurement using cone-beam CT images.*

Landmarks[†]		*Description*
Midline landmarks		
1	ST Glabella	Most anterior point of soft tissue forehead
2	ST Infra-glabella	Crosspoint between midline and corresponding to soft tissue of superior orbital margin
3	ST Nasion	Deepest point on the concavity overlying the area of the frontonasal suture
4	ST Rhinion	Closest point from tip of nasal bone, on the dorsum of nose
5	Mid-philtrum	Centered between nose and mouth
6	ST B point	Deepest point on the concavity between labiale inferius and soft tissue pogonion
7	ST Pogonion	Most prominent point of the soft tissue chin
8	Beneath chin	Vertical measure of the soft tissue on the lower edge of the chin
Bilateral landmarks		
9	ST Frontal eminence	Most anterior point of the forehead, horizontally centered on eyepupil
10	ST Supra-orbit	Horizontally centered on eyepupil, above eyebrow
11	ST Lateral nasion	Midpoint of inner canthus of the eye and soft tissue nasion
12	ST Lateral rhinion	Side of the bridge of nose, vertically at the level of end of nasal bone and horizontally on a vertical line with the inner canthus of the eye
13	ST Infra-orbit	Horizontally centered on eyepupil, under inferior orbital margin
14	ST Maxillare	Horizontally centered on eyepupil and vertically at the level of nose tip
15	Lateral nostril	Next to the most lateral point of ala nasi
16	Naso-labial ridge	The prominence next to the mid-philtrum
17	ST Supra-canina	Vertically lined up with the cheilion, on the horizontal level of the mid-philtrum
18	Upper lip	Most prominent point of the upper lip, vertically lined up with naso-labial ridge
19	Lower lip	Most prominent point of the lower lip, vertically lined up with naso-labial ridge
20	ST Infra-canina	Vertically lined up with the cheilion, on the horizontal level of the chin-lip fold
21	ST Mental tubercle	Most prominent point on the lateral bulge of the chin mound
22	ST Mid-lateral orbit	Vertically centered on the eye pupil, next to the outer canthus of the eye
23	ST Supraglenoid	Overlying soft tissue point corresponding to hard tissue Supraglenoid
24	ST Zygomatic arch	Overlying soft tissue point corresponding to hard tissue Zygomatic arch
25	ST Lateral zygoma	Center of the malar area, horizontally lined up with the outer canthus
26	ST Supra-M1	Vertically lined up with the outer canthus, on the horizontal level of the bottom of nose
27	Ante-masseter	Anterior border of the masseter, at the level of oral commissure
28	Mid-masseter	Center of the masseter, the most prominent point of the masseter area
29	ST Infra-M1	Vertically lined up with the outer canthus, on the horizontal level of the chin-lip fold
30	ST Gonion lateralis	Overlying soft tissue point corresponding to hard tissue Gonion lateralis
31	ST Mid-mandibular	Overlying soft tissue point corresponding to hard tissue Mid-mandibular
32	ST Sub-mandibular	Overlying soft tissue point corresponding to hard tissue Sub-mandibular

[†]The number which precedes the landmark name is corresponded to the number represented in the Figure 2.
ST, Soft tissue.

TABLE 3 – *Data of soft tissue thickness measurements and their comparison by measurement methods (n=20).*

Measurement (Hard tissue / Soft tissue)	*Perp HT (mm)*		*Perp ST (mm)*		*HT to ST (mm)*		*ANOVA (p value)*
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
Midline landmarks							
Glabella / ST Glabella	5.1	1.0	5.4	0.9	5.8	1.0	NS
Infra-glabella / ST Infra-glabella	5.7	0.7	5.6	0.8	6.6	1.1	0.002
Nasion / ST Nasion	6.3	1.1	5.7	1.2	7.9	1.7	0.000
Rhinion / ST Rhinion	2.6	1.0	2.4	0.9	3.0	1.0	NS
Mid-philtrum / Mid-philtrum	12.7	1.9	12.0	2.1	12.4	1.6	NS
B point / ST B point	13.0	1.5	12.3	1.2	13.2	1.6	NS
Pogonion / ST Pogonion	10.9	1.8	12.9	1.9	13.1	2.3	0.001
Menton / Beneath chin	8.0	2.0	7.1	1.4	8.1	1.8	NS
Bilateral landmarks							
Frontal eminence / ST Frontal eminence	6.5	1.2	6.7	1.3	7.3	1.2	NS
Supra-orbit / ST Supra-orbit	7.3	0.9	7.1	0.9	8.5	1.0	0.000
Lateral nasion / ST Lateral nasion	7.6	1.4	10.2	4.9	8.3	1.4	0.017
Lateral nasal end / ST Lateral rhinion	6.7	1.4	6.7	1.4	8.0	1.5	0.035
Infra-orbit / ST Infra-orbit	7.6	1.1	7.4	0.9	8.6	1.2	0.001
Maxillare / ST Maxillare	19.4	2.5	16.7	2.4	20.2	2.1	0.000
Lateral nostril / Lateral nostril	15.1	2.8	13.9	1.7	14.1	1.6	NS
Incisor alveolus / Naso-labial ridge	12.2	1.7	12.4	1.7	13.1	1.7	NS
Supra-canina / ST Supra-canina	11.1	1.2	11.1	1.1	11.1	1.2	NS
Upper incisor / Upper lip	10.1	2.1	14.0	3.0	11.5	1.6	0.000
Lower incisor / Lower lip	12.8	1.3	14.0	1.4	13.0	1.3	0.014
Infra-canina / ST Infra-canina	11.1	1.5	12.1	1.3	12.0	1.1	0.032
Mental tubercle / ST Mental tubercle	8.7	1.7	11.0	2.4	8.7	1.7	0.000
Mid-lateral orbit / ST Mid-lateral orbit	4.8	0.7	5.4	1.0	6.7	1.4	0.000
Supraglenoid / ST Supraglenoid	11.8	1.9	11.7	2.1	11.6	2.0	NS
Zygomatic arch / ST Zygomatic arch	8.2	1.4	8.3	1.3	9.0	1.5	NS
Lateral zygoma / ST Lateral zygoma	9.3	1.5	9.5	1.5	10.7	1.9	0.016
Supra-M1 / ST Supra-M1	23.5	2.5	27.2	3.8	27.2	3.3	0.001
Ante-ramus / Ante-masseter	21.9	2.7	21.1	2.7	22.0	2.7	NS
Mid-ramus / Mid-masseter	20.1	3.2	19.2	3.1	20.7	2.6	NS
Infra-M1 / ST Infra-M1	20.6	2.6	18.2	3.8	19.5	2.6	NS
Gonion lateralis / ST Gonion lateralis	11.0	2.8	14.8	2.9	10.9	2.4	0.000
Mid-mandibular / ST Mid-mandibular	14.7	2.7	13.7	2.4	13.9	1.8	NS
Sub-mandibular / ST Sub-mandibular	7.0	1.2	7.2	1.3	7.5	1.1	NS

Perp HT, Perpendicular to hard tissue; Perp ST, perpendicular to soft tissue; HT to ST, direct measurement between hard tissue and soft tissue landmarks SD, standard deviation; ST, soft tissue; NS, not significant.

TABLE 4 - *Inter-examiner reproducibility of measurements according to landmarks in case of 'perpendicular bone' method (n=20).*

Measurement	*Examiner A (mm)*		*Examiner B (mm)*		*Difference*	*Significance by t-test*	*ICC*
	Mean	*SD*	*Mean*	*SD*			
Midline landmarks							
Glabella	5.1	1.0	5.1	0.9	0.0	NS	0.932
Infra-glabella	5.7	0.7	5.7	0.7	0.0	NS	0.988
Nasion	6.3	1.1	6.2	1.2	0.1	NS	0.902
Rhinion	2.6	1.0	2.7	0.9	-0.1	NS	0.937
Mid-philtrum	12.7	1.9	12.8	2.1	-0.1	NS	0.978
B point	13.0	1.5	13.1	1.4	-0.1	NS	0.771
Pogonion	10.9	1.8	11.1	1.7	-0.2	NS	0.944
Menton	8.0	2.0	7.9	1.6	0.1	NS	0.750
Bilateral landmarks							
Frontal eminence	6.5	1.2	6.3	1.0	0.2	NS	0.936
Supra-orbit	7.3	0.9	7.2	0.9	0.1	NS	0.917
Lateral nasion	7.6	1.4	7.6	1.0	0.0	NS	0.795
Lateral nasal end	6.7	1.4	6.8	1.5	-0.1	NS	0.845
Infra-orbit	7.6	1.1	7.5	1.1	0.1	NS	0.932
Maxillare	19.4	2.5	19.3	3.0	0.1	NS	0.922
Lateral nostril	15.1	2.8	14.2	1.5	0.9	NS	0.708
Incisor alveolus	12.2	1.7	12.8	1.7	-0.6	NS	0.857
Supra-canina	11.1	1.2	10.8	1.0	0.3	NS	0.812
Upper incisor	10.1	2.1	10.5	2.1	-0.4	NS	0.969
Lower incisor	12.8	1.3	13.0	1.2	-0.2	NS	0.847
Infra-canina	11.1	1.5	11.2	1.2	-0.1	NS	0.920
Mental tubercle	8.7	1.7	8.7	1.4	0.0	NS	0.936
Mid-lateral orbit	4.8	0.7	4.7	0.9	0.1	NS	0.934
Supraglenoid	11.8	1.9	12.0	1.7	-0.2	NS	0.812
Zygomatic arch	8.2	1.4	8.3	1.3	-0.1	NS	0.979
Lateral zygoma	9.3	1.5	9.4	1.5	-0.1	NS	0.964
Supra-M1	23.5	2.5	24.2	2.8	-0.7	NS	0.923
Ante-ramus	21.9	2.7	22.3	2.5	-0.4	NS	0.937
Mid-ramus	20.1	3.2	20.0	3.2	0.1	NS	0.989
Infra-M1	20.6	2.6	20.3	2.7	0.3	NS	0.920
Gonion lateralis	11.0	2.8	11.6	2.4	-0.6	NS	0.878
Mid-mandibular	14.7	2.7	14.8	2.3	-0.1	NS	0.975
Sub-mandibular	7.0	1.2	7.2	1.4	-0.2	NS	0.910

SD, Standard deviation; ICC, intraclass correlation coefficient; NS, not significant.

TABLE 5 - *Inter-examiner reproducibility of measurements according to landmarks in case of 'perpendicular to skin' method (n=20).*

Measurement	*Examiner A (mm)*		*Examiner B (mm)*		*Difference*	*Significance by t-test*	*ICC*†
	Mean	*SD*	*Mean*	*SD*			
Midline landmarks							
ST Glabella	5.4	0.9	5.2	0.9	0.2	NS	0.823
ST Infra-glabella	5.6	0.8	5.7	0.7	-0.1	NS	0.971
ST Nasion	5.7	1.2	5.9	1.2	-0.2	NS	0.825
ST Rhinion	2.4	0.9	2.6	0.9	-0.2	NS	0.790
Mid-philtrum	12.0	2.1	12.3	1.8	-0.3	NS	0.916
ST B point	12.3	1.2	11.7	1.2	0.6	0.009	0.675
ST Pogonion	12.9	1.9	12.4	1.6	0.5	0.046	0.878
Beneath chin	7.1	1.4	7.9	2.0	-0.8	0.018	0.708
Bilateral landmarks							
ST Frontal eminence	6.7	1.3	6.2	1.0	0.5	0.009	0.871
ST Supra-orbit	7.1	0.9	7.1	0.9	0.0	NS	0.948
ST Lateral nasion	10.2	4.9	7.8	1.7	2.4	0.049	0.676
ST Lateral rhinion	6.7	1.4	7.2	1.6	-0.5	NS	0.117
ST Infra-orbit	7.4	0.9	7.4	0.8	0.0	NS	0.807
ST Maxillare	16.7	2.4	18.3	2.7	-1.6	0.000	0.918
Lateral nostril	13.9	1.7	13.9	1.7	0.0	NS	0.848
Naso-labial ridge	12.4	1.7	12.3	1.8	0.1	NS	0.970
ST Supra-canina	11.1	1.1	11.1	1.2	0.0	NS	0.629
Upper lip	14.0	3.0	12.7	2.3	1.3	0.011	0.832
Lower lip	14.0	1.4	14.3	1.4	-0.3	NS	0.749
ST Infra-canina	12.1	1.3	11.6	1.2	0.5	NS	0.786
ST Mental tubercle	11.0	2.4	12.2	1.6	-1.2	0.040	0.516
ST Mid-lateral orbit	5.4	1.0	4.7	1.0	0.7	0.006	0.595
ST Supraglenoid	11.7	2.1	12.1	1.7	-0.4	NS	0.807
ST Zygomatic arch	8.3	1.3	8.4	1.4	-0.1	NS	0.943
ST Lateral zygoma	9.5	1.5	9.6	1.7	-0.1	NS	0.896
ST Supra-M1	27.2	3.8	25.8	3.2	1.4	0.037	0.674
Ante-masseter	21.1	2.7	21.5	2.6	-0.4	0.005	0.976
Mid-masseter	19.2	3.1	20.8	3.2	-1.6	0.000	0.905
ST Infra-M1	18.2	3.8	19.9	2.8	-1.7	0.024	0.568
ST Gonion lateralis	14.8	2.9	14.0	2.8	0.8	NS	0.864
ST Mid-mandibular	13.7	2.4	14.2	1.9	-0.5	NS	0.356
ST Sub-mandibular	7.2	1.3	7.8	1.4	-0.6	0.030	0.776

SD, Standard deviation; ICC, intraclass correlation coefficient; ST, soft tissue; NS, not significant.
† The number lesser than 0.7 was underlined indicating the low inter-examiner reproducibility.

TABLE 6 - *Inter-examiner reproducibility of measurements according to landmarks in case of 'direct measurement' method (n=20).*

Measurement	*Examiner A (mm)*		*Examiner B (mm)*		*Difference*	*Significance by t-test*	*ICC*†
	Mean	*SD*	*Mean*	*SD*			
Midline landmarks							
Glabella	5.8	1.0	5.4	1.0	0.4	NS	0.589
Infra-glabella	6.6	1.1	5.8	0.7	0.8	0.002	0.575
Nasion	7.9	1.7	6.6	1.2	1.3	0.001	0.524
Rhinion	3.0	1.0	3.0	1.0	0.0	NS	0.310
Mid-philtrum	12.4	1.6	12.7	1.7	-0.3	0.006	0.958
B point	13.2	1.6	12.6	1.3	0.6	0.031	0.695
Pogonion	13.1	2.3	12.1	1.6	1.0	0.010	0.730
Menton	8.1	1.8	7.6	1.6	0.5	NS	0.748
Bilateral landmarks							
Frontal eminence	7.3	1.2	6.3	1.1	1.0	0.000	0.712
Supra-orbit	8.5	1.0	7.1	0.9	1.4	0.000	0.652
Lateral nasion	8.3	1.4	7.8	1.1	0.5	NS	0.538
Lateral nasal end	8.0	1.5	7.0	1.4	1.0	0.014	0.440
Infra-orbit	8.6	1.2	7.5	0.9	1.1	0.000	0.589
Maxillare	20.2	2.1	18.0	2.2	2.2	0.000	0.640
Lateral nostril	14.1	1.6	13.8	1.7	0.3	NS	0.901
Incisor alveolus	13.1	1.7	12.7	1.7	0.4	0.009	0.951
Supra-canina	11.1	1.2	11.1	0.9	0.0	NS	0.742
Upper incisor	11.5	1.6	11.2	1.9	0.3	0.028	0.949
Lower incisor	13.0	1.3	13.4	1.3	-0.4	NS	0.842
Infra-canina	12.0	1.1	11.7	1.4	0.3	NS	0.835
Mental tubercle	8.7	1.7	11.3	1.6	-2.6	0.000	0.701
Mid-lateral orbit	6.7	1.4	4.8	0.8	1.9	0.000	0.044
Supraglenoid	11.6	2.0	11.9	1.6	-0.3	NS	0.886
Zygomatic arch	9.0	1.5	8.4	1.4	0.6	0.001	0.939
Lateral zygoma	10.7	1.9	9.7	1.6	1.0	0.000	0.903
Supra-M1	27.2	3.3	24.5	2.6	2.7	0.001	0.691
Ante-ramus	22.0	2.7	22.0	2.6	0.0	NS	0.935
Mid-ramus	20.7	2.6	20.4	3.3	0.3	NS	0.945
Infra-M1	19.5	2.6	19.0	1.8	0.5	NS	0.886
Gonion lateralis	10.9	2.4	11.3	2.4	-0.4	NS	0.934
Mid-mandibular	13.9	1.8	14.0	1.9	-0.1	NS	0.896
Sub-mandibular	7.5	1.1	8.1	1.4	-0.6	0.043	0.699

SD, Standard deviation; ICC, intraclass correlation coefficient; NS, not significant.
† The number lesser than 0.7 was underlined indicating the low inter-examiner reproducibility.

TABLE 7 - *Intra-examiner reproducibility of the measurements in case of 'perpendicular to bone' method (n=20).*

Measurement	*1st measure (mm)*		*2nd measure (mm)*		*Difference*	*Significance by paired t-test*	*Pearson correlation coefficient*	*Reliability coefficient*
	Mean	*SD*	*Mean*	*SD*				
Midline landmarks								
Glabella	5.1	1.0	5.2	1.0	-0.1	NS	0.973*	0.986
Infra-glabella	5.7	0.7	5.8	0.7	-0.1	NS	0.982*	0.991
Nasion	6.3	1.1	6.4	1.2	-0.1	NS	0.973*	0.985
Rhinion	2.6	1.0	2.6	0.9	0.0	NS	0.917*	0.954
Mid-philtrum	12.7	1.9	12.5	2.1	0.2	NS	0.974*	0.986
B point	13.0	1.5	13.1	1.5	-0.1	NS	0.986*	0.993
Pogonion	10.9	1.8	10.8	1.7	0.1	NS	0.930*	0.963
Menton	8.0	2.0	8.0	2.0	0.0	NS	0.920*	0.958
Bilateral landmarks								
Frontal eminence	6.5	1.2	6.5	1.2	0.0	NS	0.938*	0.968
Supra-orbit	7.3	0.9	7.2	0.9	0.1	NS	0.944*	0.971
Lateral nasion	7.6	1.4	7.6	1.1	0.0	NS	0.832*	0.938
Lateral nasal end	6.7	1.4	7.0	1.4	-0.3	NS	0.913*	0.954
Infra-orbit	7.6	1.1	7.5	1.3	0.1	NS	0.966*	0.979
Maxillare	19.4	2.5	19.3	2.5	0.1	NS	0.959*	0.979
Lateral nostril	15.1	2.8	15.7	2.5	-0.6	NS	0.930*	0.949
Incisor alveolus	12.2	1.7	12.0	1.7	0.2	NS	0.953*	0.976
Supra-canina	11.1	1.2	11.2	1.4	-0.1	NS	0.919*	0.956
Upper incisor	10.1	2.1	10.3	2.1	-0.2	NS	0.964*	0.982
Lower incisor	12.8	1.3	12.8	1.1	0.0	NS	0.963*	0.974
Infra-canina	11.1	1.5	11.0	1.5	0.1	NS	0.972*	0.986
Mental tubercle	8.7	1.7	8.8	1.8	-0.1	NS	0.826*	0.904
Mid-lateral orbit	4.8	0.7	4.8	0.8	0.0	NS	0.923*	0.957
Supraglenoid	11.8	1.9	11.5	1.9	0.3	NS	0.898*	0.946
Zygomatic arch	8.2	1.4	8.2	1.3	0.0	NS	0.994*	0.995
Lateral zygoma	9.3	1.5	9.2	1.6	0.1	NS	0.990*	0.993
Supra-M1	23.5	2.5	23.6	2.8	-0.1	NS	0.938*	0.964
Ante-ramus	21.9	2.7	21.8	2.6	0.1	NS	0.993*	0.996
Mid-ramus	20.1	3.2	20.1	3.1	0.0	NS	0.989*	0.995
Infra-M1	20.6	2.6	20.5	2.5	0.1	NS	0.915*	0.956
Gonion lateralis	11.0	2.8	11.1	2.7	-0.1	NS	0.916*	0.956
Mid-mandibular	14.7	2.7	14.4	2.4	0.3	NS	0.968*	0.980
Sub-mandibular	7.0	1.2	6.9	1.1	0.1	NS	0.861*	0.922

SD, Standard deviation; NS, not significant; *p < 0.05.

TABLE 8 - *Intra-examiner reproducibility of the measurements in case of 'perpendicular to skin' method (n=20).*

Measurement	*1st measure (mm)*		*2nd measure (mm)*		*Difference*	*Significance by paired t-test*	*Pearson correlation coefficient*	*Reliability coefficient*
	Mean	*SD*	*Mean*	*SD*				
Midline landmarks								
ST Glabella	5.4	0.9	5.4	0.9	0.0	NS	0.989*	0.994
ST Infra-glabella	5.6	0.8	5.7	0.7	-0.1	NS	0.960*	0.976
ST Nasion	5.7	1.2	5.4	1.1	0.3	0.032	0.924*	0.960
ST Rhinion	2.4	0.9	2.4	0.9	0.0	NS	0.949*	0.973
Mid-philtrum	12.0	2.1	12.1	2.1	-0.1	NS	0.978*	0.989
ST B point	12.3	1.2	12.4	1.1	-0.1	NS	0.933*	0.964
ST Pogonion	12.9	1.9	12.8	1.8	0.1	NS	0.976*	0.988
Beneath chin	7.1	1.4	7.2	1.4	-0.1	NS	0.833*	0.904
Bilateral landmarks								
ST Frontal eminence	6.7	1.3	6.9	1.3	-0.2	NS	0.929*	0.963
ST Supra-orbit	7.1	0.9	7.1	0.9	0.0	NS	0.944*	0.946
ST Lateral nasion	10.2	4.9	8.1	1.4	2.1	NS	0.315	0.296
ST Lateral rhinion	6.7	1.4	7.6	1.7	-0.9	NS	0.213	0.202
ST Infra-orbit	7.4	0.9	7.6	1.1	-0.2	NS	0.790*	0.871
ST Maxillare	16.7	2.4	16.7	2.5	0.0	NS	0.972*	0.985
Lateral nostril	13.9	1.7	13.8	2.0	0.1	NS	0.835*	0.902
Naso-labial ridge	12.4	1.7	12.3	1.8	0.1	NS	0.941*	0.968
ST Supra-canina	11.1	1.1	11.0	1.0	0.1	NS	0.692*	0.815
Upper lip	14.0	3.0	14.2	3.2	-0.2	NS	0.929*	0.962
Lower lip	14.0	1.4	14.4	1.9	-0.4	NS	0.884*	0.918
ST Infra-canina	12.1	1.3	12.2	1.1	-0.1	NS	0.904*	0.956
ST Mental tubercle	11.0	2.4	10.7	2.3	0.3	NS	0.955*	0.975
ST Mid-lateral orbit	5.4	1.0	5.7	1.0	-0.3	NS	0.601*	0.751
ST Supraglenoid	11.7	2.1	11.9	2.0	-0.2	NS	0.889*	0.941
ST Zygomatic arch	8.3	1.3	8.4	1.5	-0.1	NS	0.964*	0.979
ST Lateral zygoma	9.5	1.5	9.5	1.5	0.0	NS	0.856*	0.922
ST Supra-M1	27.2	3.8	30.7	3.6	-3.5	NS	0.228	0.337
Ante-masseter	21.1	2.7	21.0	2.7	0.1	NS	0.971*	0.985
Mid-masseter	19.2	3.1	19.4	2.9	-0.2	NS	0.943*	0.970
ST Infra-M1	18.2	3.8	18.2	4.0	0.0	NS	0.971*	0.937
ST Gonion lateralis	14.8	2.9	14.6	3.2	0.2	NS	0.852*	0.918
ST Mid-mandibular	13.7	2.4	14.1	2.1	-0.4	NS	0.817*	0.893
ST Sub-mandibular	7.2	1.3	7.5	1.2	-0.3	NS	0.796*	0.885

SD, Standard deviation; ST, soft tissue; NS, not significant; *p < 0.05.

TABLE 9 - *Intra-examiner reproducibility of the measurements in case of 'direct measurement' method (n=20).*

Measurement	*1st measure (mm)*		*2nd measure (mm)*		*Difference*	*Significance by paired t-test*	*Pearson correlation coefficient*	*Reliability coefficient*
	Mean	*SD*	*Mean*	*SD*				
Midline landmarks								
Glabella	5.8	1.0	5.7	1.0	0.1	NS	0.785*	0.879
Infra-glabella	6.6	1.1	6.2	1.0	0.4	0.037	0.785*	0.874
Nasion	7.9	1.7	8.1	1.5	-0.2	NS	0.746*	0.853
Rhinion	3.0	1.0	2.8	0.9	0.2	NS	0.693*	0.818
Mid-philtrum	12.4	1.6	12.2	1.7	0.2	NS	0.926*	0.960
B point	13.2	1.6	13.2	1.6	0.0	NS	0.948*	0.973
Pogonion	13.1	2.3	12.9	2.6	0.2	NS	0.967*	0.980
Menton	8.1	1.8	8.1	1.7	0.0	NS	0.873*	0.931
Bilateral landmarks								
Frontal eminence	7.3	1.2	7.4	1.4	-0.1	NS	0.809*	0.890
Supra-orbit	8.5	1.0	8.0	1.1	0.5	0.004	0.790*	0.882
Lateral nasion	8.3	1.4	8.1	1.2	0.2	NS	0.804*	0.883
Lateral nasal end	8.0	1.5	7.9	1.4	0.1	NS	0.757*	0.860
Infra-orbit	8.6	1.2	8.0	1.2	0.6	0.005	0.724*	0.840
Maxillare	20.2	2.1	20.4	1.8	-0.2	NS	0.877*	0.930
Lateral nostril	14.1	1.6	13.6	1.6	0.5	0.019	0.855*	0.921
Incisor alveolus	13.1	1.7	12.9	1.9	0.2	NS	0.923*	0.957
Supra-canina	11.1	1.2	10.9	1.0	0.2	NS	0.855*	0.918
Upper incisor	11.5	1.6	11.0	1.7	0.5	0.007	0.902*	0.948
Lower incisor	13.0	1.3	12.7	1.4	0.3	0.003	0.962*	0.980
Infra-canina	12.0	1.1	12.1	1.2	-0.1	NS	0.760*	0.861
Mental tubercle	8.7	1.7	8.6	1.7	0.1	NS	0.922*	0.959
Mid-lateral orbit	6.7	1.4	7.2	1.6	-0.5	0.048	0.780*	0.874
Supraglenoid	11.6	2.0	11.7	1.9	-0.1	NS	0.969*	0.983
Zygomatic arch	9.0	1.5	8.4	1.5	0.6	0.004	0.880*	0.936
Lateral zygoma	10.7	1.9	10.7	1.6	0.0	NS	0.842*	0.909
Supra-M1	27.2	3.3	27.3	3.3	-0.1	NS	0.931*	0.964
Ante-ramus	22.0	2.7	21.6	2.7	0.4	0.014	0.971*	0.985
Mid-ramus	20.7	2.6	20.5	2.9	0.2	NS	0.928*	0.960
Infra-M1	19.5	2.6	19.5	2.6	0.0	NS	0.943*	0.971
Gonion lateralis	10.9	2.4	10.7	2.6	0.2	NS	0.894*	0.942
Mid-mandibular	13.9	1.8	13.7	2.0	0.2	NS	0.849*	0.915
Sub-mandibular	7.5	1.1	7.9	1.3	`-0.4	NS	0.636*	0.768

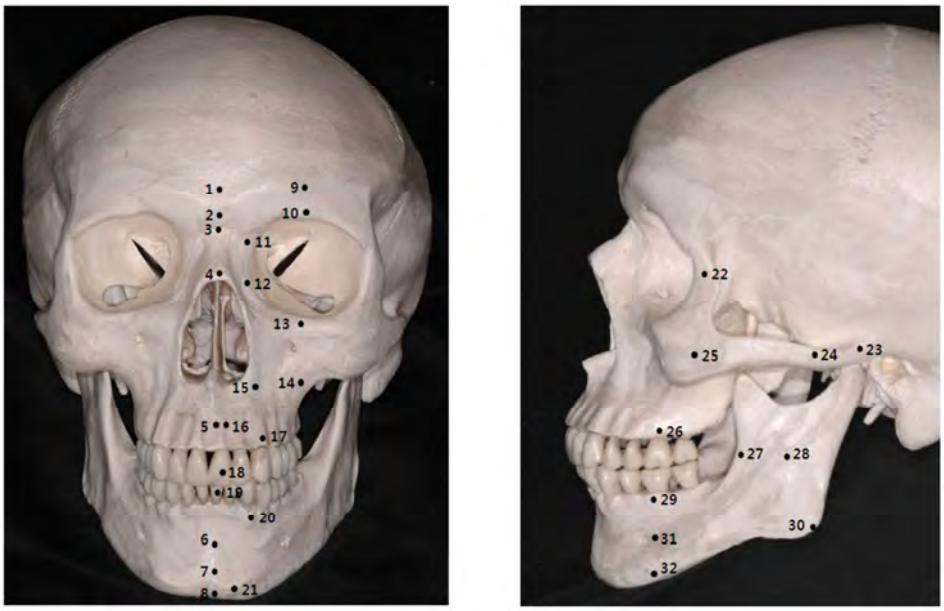
SD, Standard deviation; NS, not significant; *$p < 0.05$.

Figure legends

FIG. 1 - *Thirty two (8 midline and 24 bilateral) hard tissue landmarks used in this study. Their definitions are described on Table 1.*

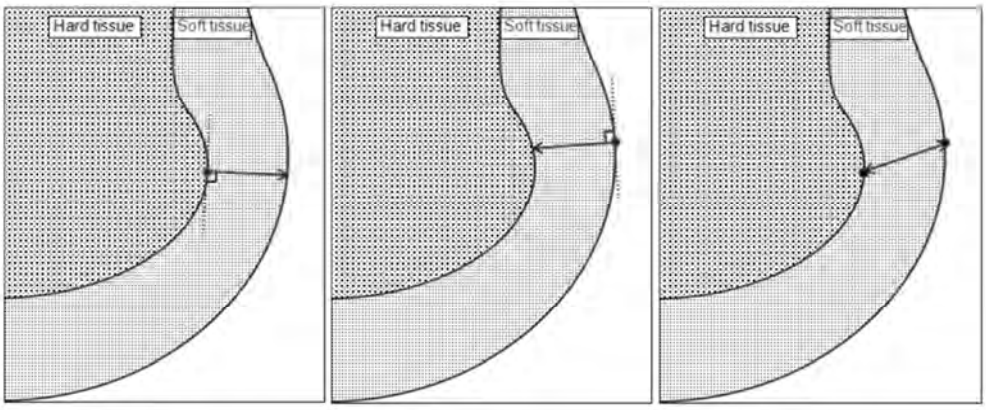
FIG. 2 - *Thirty two (8 midline and 24 bilateral) soft tissue landmarks used in this study. All landmarks were corresponded to the hard tissue landmarks seen in Figure 1 and their definitions are described on Table 2.*

FIG. 3 - *Schematic diagram showing three measurement methods used in this study. Landmarks used by each method are expressed as dots. A, measurement perpendicular to bone; B, measurement perpendicular to skin; C, direct measurement between the two landmarks, one on bone and the other on skin.*



511x328mm (72 x 72 DPI)

513x332mm (72 x 72 DPI)



352x146mm (72 x 72 DPI)

Release Form for Patient Records

For valuable considerations, receipt of which is acknowledged, I hereby grant my doctor the irrevocable right and permission, in connection with the records, including photographs and radiographs, that were taken of me or which I provided to my doctor, (copies of which records are annexed hereto and made a part hereof), the following: the right to use and reuse, in any manner at all, said records, in whole or in part, modified or altered, in scientific papers, demonstrations, and any medium or form of distribution.

Please check *one*:

✔ I am over the age of eighteen years and I have read the foregoing and fully and completely understand the contents.

_____ I represent that the subject of the photographs is a minor and that I am the parent of the minor and that I have read the foregoing and fully and completely understand the contents.

Signature: _____ Date: Feb 20, 2014

Name (please print): Ji-Hun Jung

Address: #303, 112-9 Samjeon-dong

Songpa-gu, Seoul, Korea

Parent/Guardian: _____ Date: _____

***Journal of Forensic Sciences*: Copyright Assignment Form**

Title of Article ("Article"): _____

_____

Manuscript No. (if known): _____ Manuscript Type (if known): _____

Names of all Authors in the Order in Which They Appear in the Article: _____

_____

To enable the American Academy of Forensic Sciences (AAFS) and Blackwell Publishing Inc. (Blackwell Publishing) to publish your Article in the *Journal of Forensic Sciences* (JOFS), the ownership of copyright must be established. The Article is deemed to include all material submitted for publication with the exception of Letters to the Editor, and includes the text, figures, tables, author contact details and all supplementary material accompanying the Article.

Please read this form carefully, sign at the bottom (if your employer owns copyright in your work, arrange for your employer to sign where marked), and return the signed form by mail, fax or email (see page 3 for details) as promptly as possible. US Federal Government authors please note: Your Article is in the public domain, but please check Box C and sign the form.

All Authors must sign this form before the manuscript can be published in the JOFS. The rights conveyed in this assignment will only apply upon acceptance of your Article for publication.

Acceptance for publication in the JOFS is the responsibility of the Editorial Board and the Editor, and occurs only after review in accordance with the Policies and Procedures of the JOFS and Blackwell Publishing.

Your Article will not be published unless a Copyright Assignment Form has been signed by all Authors and received by the *Journal of Forensic Sciences*, the official journal of AAFS.

Please note: You retain the following rights to re-use the Article, as long as you do not sell or reproduce the Article or any part of it for commercial purposes (i.e. for monetary gain on your own account or on that of a third party, or for indirect financial gain by a commercial entity). These rights apply without needing to seek permission from the JOFS.

- **Prior to acceptance:** We ask that as part of the publishing process you acknowledge to others that the Article has been submitted to the JOFS. You will not prejudice acceptance if you use the unpublished Article, in form and content as submitted for publication in the JOFS, in the following ways:
  - sharing print or electronic copies of the Article with colleagues;
  - posting an electronic version of the Article on your own personal website, on your employer's website/repository and on free public servers in your subject area.
- **After acceptance:** Provided that you give appropriate acknowledgement to the JOFS, AAFS and Blackwell Publishing, and full bibliographic reference for the Article when it is published, you may use the accepted version of the Article as originally submitted for publication in the JOFS, and updated to include any amendments made after peer review, in the following ways:
  - you may share print or electronic copies of the Article with colleagues;
  - you may use all or part of the Article and abstract, without revision or modification, in personal compilations or other publications of your own work;
  - you may use the Article within your employer's institution or company for educational or research purposes, including use in course packs;
  - after 12 months, you may post an electronic version of the Article on your own personal website, on your employer's website/repository and on free public servers in your subject area. Electronic versions of the accepted Article must include a link to the published version of the Article together with the following text: 'The definitive version is available at www.blackwell-synergy.com', and through www.aafs.org.

Please note that you are not permitted to post the Blackwell Publishing PDF version of the Article online.

All requests by third parties to re-use the Article in whole or in part will be handled by Blackwell Publishing. Any permission fees will be retained by the JOFS. All requests to adapt substantial parts of the Article in another publication (including publication by Blackwell Publishing) will be subject to your approval (which is deemed to be given if we have not heard from you within four weeks of your approval being sought by us writing to you at your last notified address). Please address any queries to journalsrights@oxon.blackwellpublishing.com.

In signing this Agreement:

1. You hereby assign rights in the Article to AAFS;
2. You hereby warrant that this Article is an original work, has not been published before and is not being considered for publication elsewhere in its final form either in printed or electronic form;
3. You hereby warrant that you have obtained permission from the copyright holder to reproduce in the Article (in all media including print and electronic form) material not owned by you, and that you have acknowledged the source;
4. You hereby warrant that this Article contains no violation of any existing copyright or other third party right or any material of an obscene, indecent, libellous or otherwise unlawful nature and that to the best of your knowledge this Article does not infringe the rights of others;
5. You warrant that any formula or dosage given is accurate and will not if properly followed injure any person;
6. You will indemnify and keep indemnified the JOFS Editor, AAFS, and Blackwell Publishing against all claims and expenses (including legal costs and expenses) arising from any breach of this warranty and the other warranties on your behalf in this Agreement.

By signing this Agreement you agree that AAFS may arrange for the Article to be:

- Published in the JOFS, and sold or distributed, on its own, or with other related material;
- Published in multi-contributor book form or other edited compilations by Blackwell Publishing, and others with the permission of AAFS;
- Reproduced and/or distributed (including the abstract) throughout the world in printed, electronic or any other medium whether now known or hereafter devised, in all languages, and to authorize third parties (including Reproduction Rights Organizations) to do the same;
- You agree to AAFS and Blackwell Publishing, with the permission of AAFS, using any images from the Article on the cover of the JOFS, and in any marketing material.

You authorize AAFS to act on your behalf to defend the copyright in the Article if anyone should infringe it, although there is no obligation on AAFS to act in this way, and you agree to provide all relevant documentation and evidence needed by AAFS, and to otherwise provide aid to AAFS, in any such actions.

AAFS undertakes that every copy of the Article published by Blackwell Publishing will include the full bibliographic reference for your Article, together with the copyright statement.

Each author must complete one of the signature blocks below and must check Box A, B or C. Respective descriptions are:

Box A: To be Checked if Copyright Belongs to You
You hereby assign to AAFS copyright in the Article including the abstract for the full period of copyright and all renewals, extensions, revisions and revivals throughout the world in any form and in all languages. AAFS may assign the rights granted in this Copyright Assignment Form.

Box B: To be Checked if Copyright Belongs to Your Employer (e.g. HMSO, CSIRO)
The copyright holder grants AAFS an *exclusive* licence to publish the Article including the abstract in printed and electronic form, in all languages, and to administer subsidiary rights agreements with third parties for the full period of copyright and all renewals, extensions, revisions and revivals thereof.

Box C: To be Checked if the Article is in the Public Domain (e.g. US Federal Government Employees)
You certify that the Article is in the public domain. No licence to publish is therefore necessary.

Corresponding Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Corresponding Author (*Required*): Hyeon-Sik Hwang **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): Yanan Hou **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): Seen yeong Choo **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): J:-Sup Hwang **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address** : _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): Moon Da-nal **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): _____ **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address**: _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): _____ **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Co-Author's Name: _____ **Address** : _____

Phone: _____ **Fax:** _____ _____

Email: _____ _____

Please Check One (*Required*): ☐ **Box A** ☐ **Box B** ☐ **Box C** _____

If you have checked Box B, please print name of Copyright Holder:

_____

This will be printed on the copyright line on each page of the Article. It is your responsibility to provide the correct information of the copyright holder.

Signature of Co-Author (*Required*): _____ **Date:** _____

If your employer claims copyright in your work, this form must also be signed below by a person authorized to sign for and on behalf of your employer, as confirmation that your employer accepts the terms of this licence.

Signature (on behalf of the employer of the author/s): _____

Print Name of Employer: _____ **Date:** _____

Please Mail the Signed Copyright Assignment Form to:

Journal of Forensic Sciences
6700 Woodlands Parkway, Suite 230-308
The Woodlands, TX 77381 USA

Or Fax to (1) 281 419 6236
Or Email a PDF to jfs.editor@att.net